SOME NEW MATHEMATICAL METHODS FOR VARIATIONAL OBJECTIVE ANALYSIS

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Final Report

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Summary

During this extremely productive period, numerous results were obtained relevant to remote sensing, variational objective analysis and data assimilation. A list of publications relevant in whole or in part is attached below. The principal investigator gave many invited lectures, disseminating the results to the Meteorological Community as well as the Statistical Community. A list of invited lectures at meetings is attached, as well as a list of departmental colloquia at various universities and institutes. This work is continuing under a follow on Grant.

Publications

G. Wahba, Bayesian confidence intervals for the cross validated smoothing spline. *J. Roy. Stat. Soc. B.*, **45**, 1, 133-150 (1983).

F. O'Sullivan and G. Wahba, The analysis of some penalized likelihood estimation schemes, PhD thesis, Dept. of Statistics, University of Wisconsin, Madison, WI. TR 726 (1983)

G. Wahba, Surface fitting with scattered, noisy data on Euclidean d-space and on the sphere. *Rocky Mountain J. Math.*, **14**, 1, 281-299 (1984).

G. Wahba, Cross validated spline methods for direct and indirect sensing experiments. In "Statistical Signal Processing", E.J. Wegman and J. Smith, eds., Marcel Dekker (1984).

G. Wahba, Cross validated spline methods for the estimation of multivariate functions from data on functionals. In "Statistics, an Appraisal, Proceedings of the Iowa State University Statistical Laboratory 50th Anniversary Conference" H.A. David and H.T. David, eds. The Iowa State University Press, 205-235 (1984).

F. O'Sullivan and G. Wahba, A cross validated Bayesian retrieval algorithm for non-linear remote sensing experiments. *J. Comput. Physics*, **59**, 441-455 (1985).

G. Wahba, Design Criteria and eigensequence plots for satellite computed tomography. *J. Atmos. Ocean Techn.*, **2**, 2, 125-132 (1985).

G. Wahba, A comparison of GCV and GML for choosing the smoothing parameter in the generalized spline smoothing problem. *Ann. Statist.* **13**, 1378-1402 (1985).

G. Wahba, Variational methods for multidimensional inverse problems, in "Remote Sensing Retrieval Methods", A. Deepak, H.E. Fleming and M.T. Chahine, eds., A. Deepak Publishing Co., pp. 385-408 (1985).

G. Wahba, Multivariate thin plate spline smoothing with positivity and other linear inequality constraints, in "Statistical Image Processing and Graphics", E. Wegman and E.J. dePriest, eds., Marcel Dekker (1985).

G. Wahba, Partial spline modeling of the tropopause and other discontinuities in *Function Estimates, Contemporary Mathematics Volume 59*, American Mathematical Society, Providence, R.I., pp. 125-135 (1986).

G. Wahba, Partial spline models for the estimation of three dimensional atmospheric temperature distribution from satellite radiance data and tropopause height information. In "Variational Methods in Geosciences", Y.K. Sasaki, ed. Elsevier, 125-130 (1986).

G. Wahba, J.-J. Shiau and D.R. Johnson. Partial spline models for the inclusion of tropopause and frontal boundary information in otherwise smooth two and three dimensional objective analysis. *J. Ocean Atmos. Tech.*, 714-725 (1986).

M. Villalobos and G. Wahba, Inequality-constrained multivariate smoothing splines with application to the estimation of posterior probabilities. *J. Amer. Statist. Assoc.* **82**, 239-248 (1987).

D. Bates, M. Lindstrom, G. Wahba,and B. Yandell. GCVPACK-routines for generalized cross validation. *Commun. Statist., Simulation and Computation*, **16**, 263-297 (1987).

G. Wahba, Three topics in ill posed inverse problems. In "Inverse and Ill-Posed Problems", M. Engl and G. Groetsch, eds., Academic Press, 37-51 (1987).

G. Wahba, Partial and interaction spline models, in "Bayesian Statistics 3, J.M. Bernardo, M.M. deGroot, D.V. Lindley and A.F.M. Smith, eds, Oxford University Press 479-491 (1988).

J.-J. Shaiu and G. Wahba, Rates of convergence of some estimators for a semiparametric model. *Commun. Statist. Comp.* **17**, 1117-1133 (1988).

G. Wahba, Multiple smoothing parameters in semiparametric multivariate model building. In "Computing Science and Statistics", Proceedings of the 20th Symposium on the Interface, E.J. Wegman, ed., American Statistical Association, Washington, D.C., 435-441 (1989).

G. Wahba, Spline Functions. Entry in the Encyclopedia of Statistical Sciences, Suppl. Vol., S. Kotz and N.L. Johnson, eds., 148-160 (1989).

G. Wahba, On the dynamic estimation of relative weights for observation and forecast in numerical weather prediction, in "RSRM '87: Advances in Remote Sensing Retrieval Methods", A. Deepak, H.E. Fleming and J.S. Theon, eds., A. Deepak Publishing Co., Hampton, VA, 347-358 (1989).

C. Gu and G. Wahba, RKPACK and its applications: fitting smoothing spline models, *in* 'Proceedings of the Statistical Computing Section', C. Gu, American Statistical Association, pp. 42–51.(1989). Code available thru `netlib`.

C. Gu, D. Bates, Z. Chen and G. Wahba, The computation of GCV functions through Householder tridiagonalization with application to the fitting of interaction spline models. *SIAM J. Matrix Anal.*, **10**, 457-480 (1989)

G. Wahba, "Spline Models for Observational Data" Vol. 59 in the CBMS-NSF Regional Conference Series in Applied Mathematics. SIAM, Philadelphia, PA (1990). xii + 169 pp.

G. Wahba, Regularization and cross validation methods for nonlinear implicit, ill-posed inverse problems. In "Geophysical Data Inversion Methods and Applications", A. Vogel, C. Ofoegbu, R. Gorenflo and B. Ursin, eds., Vieweg, Wiesbaden-Braunschweig, 3-13 (1990).

G. Wahba,and Y. Wang. When is the optimal regularization parameter insensitive to the choice of the loss function? *Commun. Statist.*, **A19**, 5 1685-1700, (1990).

G. Wahba, F. Reames and D.R. Johnson. Multiple smoothing and weighting parameters in direct variational methods for objective analysis of meteorological information. In "Assimilation of Observations in Meteorology and Oceanography", Proceedings of the WMO International Symposium, Clermont-Ferrand, 1990, F.- X. LeDimet and O. Talagrand, eds., WMO, 448-453 (1991).

C. Gu and G. Wahba, Minimizing GCV/GML scores with multiple smoothing parameters via the Newton methods. *SIAM J. Sci. Stat. Comput.* **12**, 383-398 (1991).

G. Wahba, Multivariate model building with additive, interaction, and tensor product thin plate splines. In "Curves and Surfaces" , P.-J. Laurent, A. Le Mehaute and L. L. Schumaker, eds., Academic Press, 491-504 (1991).

G. Wahba, Multivariate function and operator estimation, based on smoothing splines and reproducing kernels, in "Nonlinear Modeling and Forecasting, SFI Studies in the Sciences of Complexity", Proc. Vol. XII, Eds. M. Casdagli and S. Eubank, Addison-Wesley, 95-112 (1992).

F. Gao, (1992), On combining data from multiple sources with unknown relative weights, TR 894, Dept. of Statistics, University of Wisconsin, Madison, WI (1992).

C. Gu and G. Wahba, Smoothing spline ANOVA with component-wise Bayesian "confidence intervals". *J. Graph. Comput. Statist.*, **2**, 97-117 (1993)

D. Bates, F. Reames and G. Wahba, Getting better contour plots with S and GCVPACK. *Comp. Stat. Data Anal.*, **15**, 329-342 (1993).

C. Gu and G. Wahba, Semiparametric ANOVA with tensor product thin plate splines. *J. Roy. Stat. Soc. B*, **55**, 353-368 (1993).

F. Gao. On combining data from multiple sources with unknown relative weights (thesis), TR 902, Dept. of Statistics, University of Wisconsin, Madison, WI (1993).

F. Gao. Fitting smoothing splines to data from multiple sources. *Commun. Statist. - theory Meth.* **23**, 1665–1698 (1994)

G. Wahba, D. R. Johnson, F. Gao and J. Gong, Adaptive tuning of numerical weather prediction models: Part I: randomized GCV and related methods in three and four dimensional data assimilation, *Monthly Weather Review*, invited revision in preparation (Also TR 920).

Three papers the series beginning with the previous item, and partially supported by NAG5-316 are in preparation under a follow on grant.

Invited Conference and Workshop Lectures

Presented by G. Wahba:

Durham, England Symposium on the Numerical Treatment of Integral Equations, July 1982.

50th Anniversary Celebration of the Iowa State University Statistical Laboratory, June 1983.

U.S.-Japan Statistical Time Series Analysis Seminar, Tokyo, May 1984.

NSF Workshop on New Multivariate Methods, Bowdoin, ME, June 1984.

IFOARS Workshop on Advances in Remote Sensing Retrieval Methods, Williamsburg, October 1984.

Midwest Statistics Conference, Bloomington, IN, November 1984.

NSF Workshop on Efficient Data Collection and Related Inference, Los Angeles, July 1985.

NSF Workshop on Function Estimates, Arcata, CA, July 1985.

ISI Satellite Meeting, Maastrich, Netherlands, August 1985.

International Symposium on Variational Methods in the Geosciences, Norman, OK, October 1985.

Interface Symposium, Fort Collins, CO, March 1986.

Alpine-U.S. Seminar on Inverse and Ill-Posed Problems, Austria, June 1986.

American Statistical Association National Meeting, Chicago, August 1986.

International Workshop on Multivariate Approximation, Santiago, Chile, December 1986.

Conference Board of the Mathematical Sciences (CBMS)–An NSF-Sponsored Conference organized around 10 lectures given by G. Wahba at Ohio State, March 1987.

Second Symposium on Complexity of Approximately Solved Problems, Columbia University, April 1987.

Third Valencia International Meeting on Bayesian Statistics, Spain, June 1987.

International Workshop on Remote Sensing Retrieval Methods, Williamsburg, VA, December, 1987.

Conference on Approximation Theory, Oberwolfach, Germany, February 1988.

1988 Interface: Symposium on the Interface between Computer Science and Statistics, Washington, D.C., April 1988.

SIAM Conference on Applied Linear Algebra, Madison, WI, May 1988.

Seventh International Seminar on Model Optimization in Exploration Geophysics, Free University of Berlin, February 1989.

Third Symposium on Complexity of Approximately Solved Problems, Columbia University, April 1989.

Texas A&M Symposium on Modern Statistical Science in Celebration of the 60th Birthday of Emanuel Parzen, Texas A&M, April 1989.

1989.
American Mathematical Society Regional Meeting, Muncie, IN, October 1989.
International Conference on Curves and Surfaces, Chamonix, France, June 1990.
Second World Congress of the Bernoulli Society for Mathematical Statistics and Probability, Uppsala, Sweden, August 1990.
Stochastic Mathematics, Oberwolfach, Germany, March 1991.
Trends in the Analysis of Curve Data, Heidelberg, Germany, March 1991.
Thirteenth World Congress on Computation and Applied Mathematics (IMACS 91), Dublin, July 1991.
Third International Conference on Environmetrics, Madison, WI, October 1991.
Numerical Methods of Approximation Theory, Oberwolfach, Germany, November 1991.
Math Sciences Research Institute, Statistics Workshop, Berkeley, CA April 1992.
Nordic Conference of Mathematical Statistics, (Keynote Speaker, Three Hour Talks), Roros, Norway, June 1992.
Inst. Math. Applic., Minneapolis, MN, Environmental Studies Workshop, July 1992.
Workkshop on Adjoint Applications in Dynamic Meteorology, Asilomar, CA, August, 1992.
Interface 93, San Diego, CA, April 1993.
Third SIAM Conference on Linear Algebra, Seattle, WA, August 1993. (J. Gong gave the talk.)
Assimilation of Meteorological and Oceanographical Observations, Toulon, France, August 1993.
Second Workshop on Adjoint Applications in Dynamic Meteorology, Visegrad, Hungary May 1994.
Workshop on Modeling the Earth's Climate, Boulder, CO, July 1994.
SIAM National Meeting (Plenary Lecture), San Diego, CA, July 1994.

Lectures at Universities and Research Institutes

Presented by G. Wahba:
Courant Institute
Cornell University
Harvard University
National Bureau of Standards
National Center for Atmospheric Research
Australian National University, Canberra
Flinders University, Adelaide
University of Queensland, Brisbane
Australian Numerical Meteorological Research Center, Melbourne
Academic Sinica, Taiwan
Yale University
AT&T Bell Labs
Geophysical Fluid Dynamics Lab, Princeton

University of California,Berkeley, University of Chicago
University of Michigan-Ann Arbor
Purdue University
Iowa State University-Ames
Stanford University
University of Washington, Seattle